A Sample Caching Concept for Planetary Missions

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Abstract—A Sample Caching Subsystem (SCS) concept that provides transfer and storage of core and soil samples for planetary missions has been developed. The SCS could be carried on a rover and a rover arm-mounted coring tool could acquire samples and deposit the samples in the SCS. The SCS would transfer the samples into a sample container, with each sample in a separate sleeve. Important to the SCS design is the ability to seal each sleeve, and the sample with it, to isolate it from other samples and from the external environment. Sealing of the samples will allow for maintaining the integrity of organic materials over many years thereby allowing the samples to be analyzed in later missions or after a return trip to Earth. [1] [2]

TABLE OF CONTENTS

1. INTRODUCTION

The process of sample caching stores samples for their later use either in the current mission or in a later mission. The Sample Caching Subsystem (SCS), shown in Figure 1, has been designed to cache samples for planetary missions. The target applications are Mars missions but the concept could be applied to other sample acquisition missions also. Important design features of the SCS include allowing for isolation of samples from each other, sealing of samples, and interface to a relatively coarsely controlled sampling tool.

An example scenario for sample caching is a Mars rover that acquires samples and stores the samples in a container on the rover. The rover could return the container to a lander for use in that mission or leave the container on the Martian surface for use by a later mission. A lander could analyze the samples with in-situ instruments or it could be part of a sample return mission where the container is transferred to a Mars ascent vehicle and returned to Earth. The container could be left on the Martian surface either on the rover or the rover could place the container on the ground.

Sealing of samples separately from other samples will be important for many mission scenarios. Individually sealing samples will prevent cross contamination with samples acquired at different geographic sites. Sealing of samples will prevent degradation of samples that could be caused by exposure to the Martian surface environment. Samples individually sealed in a container could maintain their scientific value for decades while waiting on the Martian surface for a subsequent mission to retrieve them.

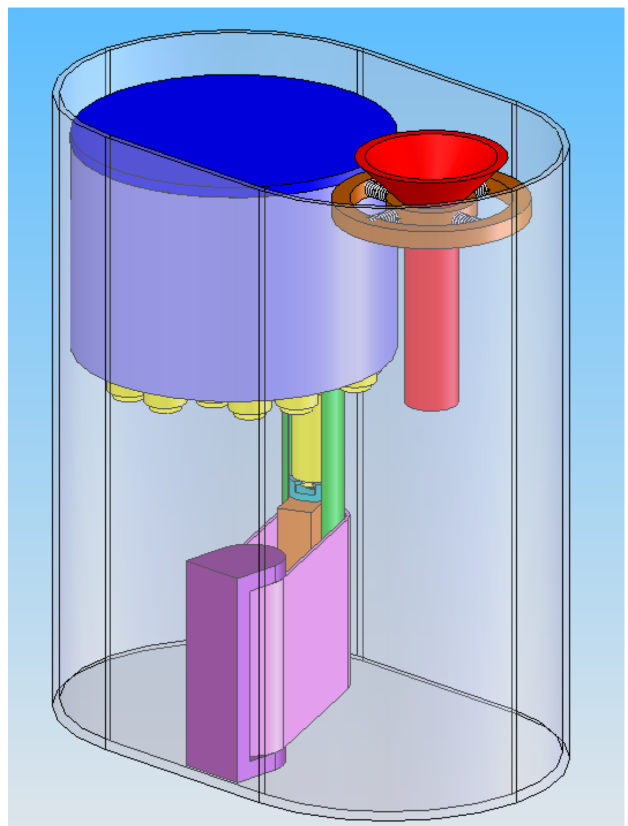

Figure 1. Sample Caching Subsystem

Leaving a sample cache in a container on the surface of Mars could allow for important mission scenarios. A mission with a highly mobile rover can collect and cache samples in a container and leave the container on the Mars surface for use in a later, perhaps much later, mission. The container of samples could be left on the rover or placed on the ground. If left on the rover, then the rover would

1

[1] 1-4244-0525-4/07/$20.00 ©2007 IEEE.
[2] IEEEAC paper #1343, Version 2, Updated December 29, 2006

purposely go to a benign area and wait there for the subsequent mission that would use the cache so that the rover is not in jeopardy of dying in an inaccessible location. A simple way to transfer the cache from one mission to the next is for the sampling rover to fill the container and then drive to a benign location and place the container on the ground there. A later mission would then have a benign location to land and retrieve the cached samples. The later mission could then use samples cached in the earlier mission and therefore not need to provide the mobility and sample acquisition capability of the previous mission. The later mission could analyze the samples in-situ or it could be a sample return mission which retrieves the sample container and returns it to Earth. Caching of samples has been recommended for future Mars rover missions by the NASA Mars Exploration Program Analysis Group (MEPAG) and by the National Research Council [11,12].

An individual sample storage approach was developed for a previous Mars Sample Return (MSR) mission concept [1]. In this approach, each sample is stored in its own sample tube and a cap is placed on each sample tube. The sample tubes could then be individually handled. Conceptually, a sealing technique would be developed that allows the caps to seal the samples inside the tubes.

The Soviet Union's Luna 16, 20, and 24 missions returned samples to Earth from the Moon. An extendable arm placed a drill onto the surface to collect soil samples [5]. A column of regolith in the drill tube was transferred to a soil sample container that was hermetically sealed for return to Earth.

Astronauts collected soil and rock samples that were returned to Earth in Apollo missions. Various types of tools and sample storage containers were used [6]. Drive tubes were used to collect regolith samples. Caps were placed on the ends of the core tubes to contain the sample for return to Earth. The Special Environmental Sample Container (SESC) was one of the containers used to store samples for return to Earth. A knife-edge seal was pressed into an indium alloy metal to insure that the sample inside was not exposed to spacecraft or terrestrial contaminants. The Apollo Lunar Sample Return Container (ALSRC) was an aluminum box to store samples to be returned to Earth. The ALSRC had a triple seal: a knife edge in soft indium alloy metal and two fluorosilicone o-rings. The lunar dust posed a significant challenge for sealing the containers [10].

A sample return container was developed for sample return from a comet [4]. The container has multiple individual sample canisters. A sealing cap is pressed onto each canister to provide a hermetic seal.

Cached samples will need to maintain their scientific value while waiting to be used [7,8,9]. The cache container will need to provide protection for the samples from interaction with the environment such as from heat or environmental gases.

2. REQUIREMENTS FOR SAMPLE CACHING

The SCS was designed to enable caching of samples for long-term storage. The sample container size was chosen to be consistent with its possible return in a later Mars Sample Return mission [1,2,3], about 9cm in diameter.

A sample caching subsystem needs to allow for the samples to be placed in a container and for the samples to be preserved. The container needs to be consistent with the size that could be returned in a Mars Sample Return mission. The container needs to be able to be dropped on the ground for retrieval in a later mission. It needs to be able to cache core, soil, and atmospheric samples. It needs to keep the samples separated to prevent cross-contamination and be able to identify where each sample was acquired. Samples need to be sealed to prevent exposure to the external environment. The design needs to minimize cost, mass, and volume. The caching subsystem needs to be compatible with the sample acquisition system.

3. DESIGN CONSIDERATIONS

It was assumed that the samples would be acquired using a tool on a manipulator arm on a rover. The samples would then need to be transferred from the tool into the container. Within this context, there were various challenges that had to be overcome in the design of the SCS. The tool had to be precisely aligned with where the sample was being deposited. The sample could not overfill the volume in which it was being placed. The system needed to be as compact and simple as possible.

Various top-loading approaches were considered but the bottom-loading approach described here was finally selected. Top-loading approaches considered had problems with means for alignment of the coring tool with the container holes, hermetic sealing of the container, and accommodation of over-filling.

4. DESIGN OF THE CACHING SUBSYSTEM

The SCS design concept is shown in Figure 1. Figure 2 shows the system by functional elements. Samples are stored in individual sleeves in the sample container. The empty, unused, sleeves are stored in the container. The operations process is described below.

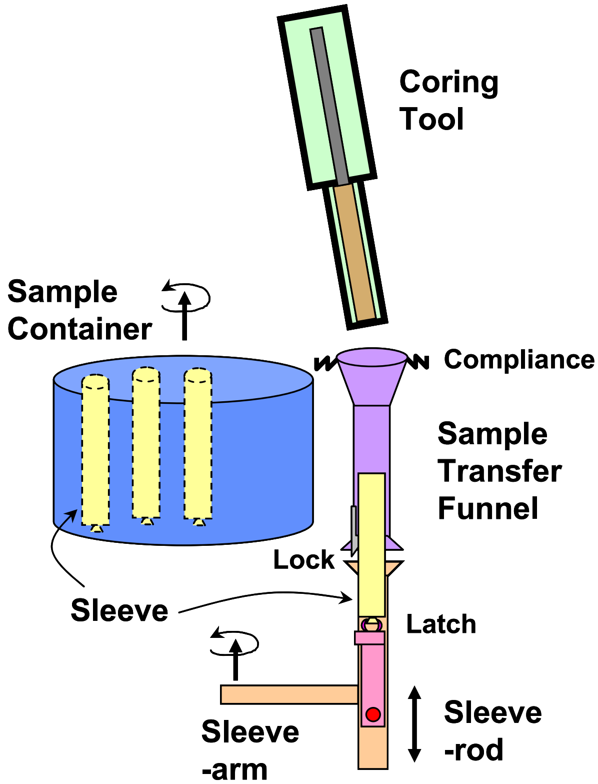

Figure 2. Sample Caching Subsystem Functional Elements

1. The sleeve-arm rotates under the sample container and the sample container rotates to enable alignment of the sleeve-rod under an empty sleeve.

2. The sleeve-rod translates up and a latch at the top of the sleeve-rod grasps a sleeve. The sleeve is then pulled down and out of the container.

3. The sleeve-arm rotates to place the sleeve under the sample transfer funnel.

4. The sleeve is pushed up into the sample transfer funnel and the funnel passively complies to provide the required precision alignment.

5. When the sleeve is all the way into the funnel, it is held in place by friction.

6. The sleeve rod latch releases the sleeve and retracts from the funnel. As it retracts, a sleeve-lock passively locks the sleeve in the funnel by rotating a lip under it. The sleeve-rod pushes the lock away when it is extended all the way to the funnel. Friction is sufficient to hold the sleeve in the funnel with out external forces, but the lock is needed to hold the sleeve in the funnel when the sample is being pushed into it from above.

7. The sampling tool moves down and pushes against the chamfer of the funnel and the funnel passively complies to align with the tool.

8. The sampling tool pushes the sample into the sleeve that is in the funnel.

9. When the sampling tool has deposited the sample in the sleeve, it then retracts from the funnel. The funnel then returns to its nominal position.

10. The sleeve-arm is already under the funnel and the sleeve-rod extends up to the sleeve. As the sleeve-rod reaches the sleeve, it pushes the sleeve-lock out of the way.

11. The latch on the sleeve-rod grasps the sleeve and the sleeve is pulled down and out of the funnel.

12. The sleeve-arm rotates to under the sample container and the sample container rotates to align the sleeve with its storage cylinder.

13. The sleeve is pushed up into its storage cylinder all the way to the top which passively engages the seals between the top of the sleeve and its storage cylinder.

14. The sleeve-rod latch releases the sleeve and the sleeve-rod retracts from the sample container. The sleeve is now sealed in the sample container.

Unused sleeves are stored in the sample container partially sticking out of the bottom of the sample container. They are held by a temporary seal that holds them in place during launch and transit to the Martian surface and until they are pulled out for use. They are not pushed all the way into the container before use so that the seals at the top of a sample cylinder are never touched until a filled sample sleeve is pushed all the way into the sample container.

Use of the sample transfer funnel decouples the precision alignment of the sleeve with the sample container from the alignment capabilities of the arm on the coring tool. The funnel passively complies with the position of the sleeve when it is being inserted from below by the sleeve-rod. The funnel separately passively complies with the coring tool position and orientation when it is depositing the sample into the sleeve. This allows for coarse positioning capability by the sampling arm and minimal impact on sampling arm requirements to support sample caching. The precision positioning capability of the sleeve-arm and sample container allows for tight packing of the sample sleeves in the sample container. We have calculated that approximately 35 sleeves could be stored in a 9cm diameter sample container with 10 mm sleeves in 11 mm holes with 2 mm spacing between holes.

The SCS has three active degrees of freedom (DOFs) plus the sleeve-rod latch. A motor with gear train would rotate the sample container. A motor with gear train would rotate the sleeve-arm. An actuator would provide translation of the sleeve-rod; alternative designs for this have been considered. The latch could be activated with a solenoid.

Sample contamination by Earth-source contaminants is a critical issue for sample caching. It is anticipated that a sample caching subsystem will need to be enclosed in a clean box with an access port on top, as shown in Figure 3. Depending on the cleanliness level of the rover, Earth-source contaminants could potentially be shed from the rover. The clean box would isolate the SCS from these contaminants. Other means would need to be used to keep the sample acquisition system clean to prevent contamination of samples prior to their transfer to the SCS.

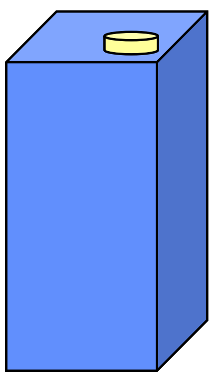

Figure 3. Clean box for SCS

The access port would open to provide access to the SCS funnel for the sampling tool to deposit the sample in the SCS. The means for actuation of the access port has not been determined; actively opening the port with an actuator is one approach, but passive access is also being considered. It is anticipated that the sample container could drop directly through the bottom of the clean box to the Martian surface. This could be done by having a passive spring holding the bottom of the box closed or by having a bottom that the container would break through when dropped. Simplicity and robustness of the design are key criteria for the final system design.

Figure 4. shows a bottom view of the SCS within the clean box. It shows that the sleeve-arm can rotate between under the sample container and under the funnel. Also, the sleeve-arm can rotate away from under the sample container to allow the sample container to drop down vertically to the Martian surface.

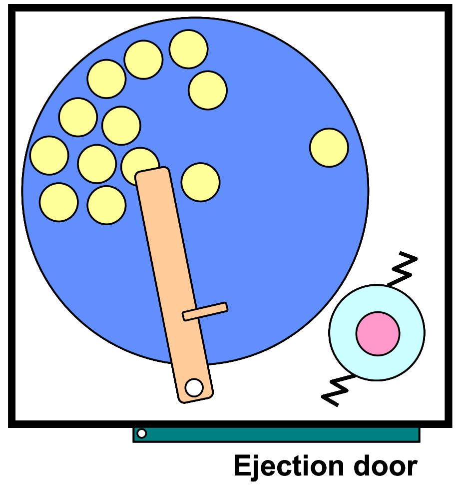

Figure 4. SCS bottom view

Figure 4 also shows the ejection door. The ejection door allows for discarding of a sleeve. A sleeve might need to be discarded if it is overfilled and cannot be inserted into the sample container. A sleeve could be overfilled by having a core break and pieces enter the sleeve unevenly, thus taking up more volume than an intact core. Top-loading designs considered had the problem that over-filled tubes could not be accommodated. The ejection door is held closed by a spring and the sleeve arm opens it by pushing it open. When outside the ejection door, the sleeve is unlatched and it then falls off. By being able to discard a sleeve, a problem with storage of one sample does not jeopardize the mission.

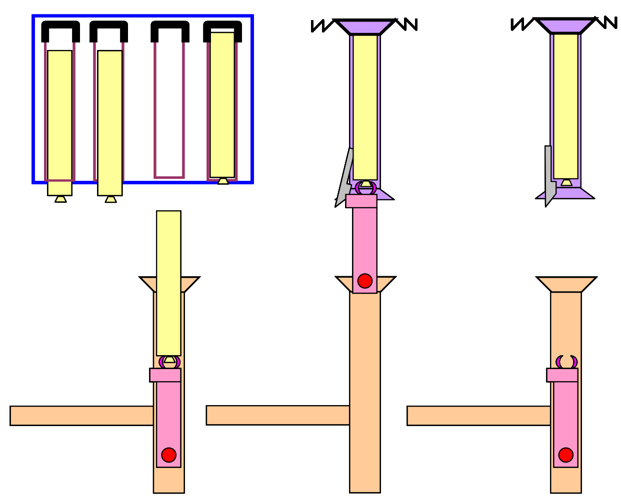

Figure 5. SCS side view

Figure 5 shows a side view of the SCS in three different stages of the sample transfer process, retrieval/insertion of the sleeve in the sample container, insertion/removal of sleeve at the funnel, and sleeve locked in the funnel. The seals are shown at the top of the sample cylinders in the sample container.

Figure 6 shows the passive alignment of the funnel and sleeve with the sampling tool. As the sampling tool pushes against the chamfer of the funnel, the funnel passively aligns with the sampling tool. The compliance of the funnel can be very soft so that the sampling tool feels very little forces of interaction with the funnel. After alignment, the sampling tool can deposit the sample into the sleeve. When complete, the sampling tool retracts and the funnel returns to its nominal position.

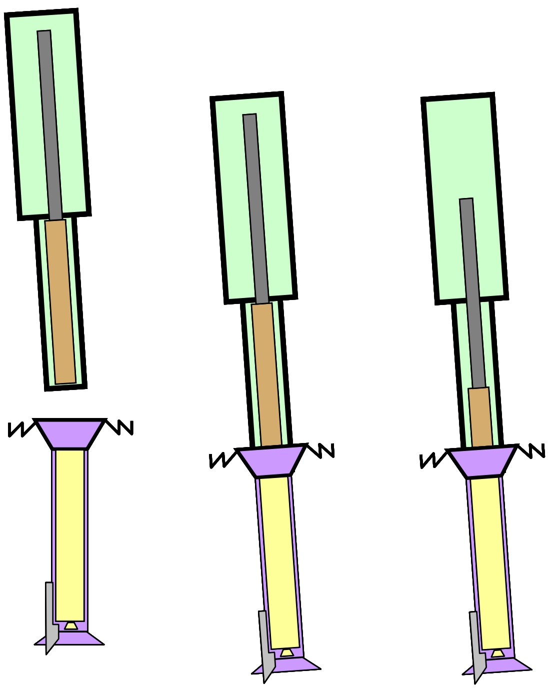

Figure 6. Passive compliance of funnel with sampling tool

Three potential types of samples are expected for the SCS, cores, soil, and atmosphere. Core and soil samples would be deposited into a sleeve at the funnel by the sampling tool. It is anticipated that an atmospheric sample would be acquired directly into a sample cylinder volume in the sample container with a seal unique for the atmospheric sample.

The approach for sealing of the sleeves in the sample container has not yet been determined. The seals will need to satisfy various requirements. Once sealed, there can be no gas leakage into or out of a sleeve. The seals themselves cannot contain contaminants. The seals need to keep the samples sealed until purposely opened potentially many years later. The seal design is a significant challenge that remains for the SCS system design.

5. CONCLUSIONS

The Sample Caching Subsystem provides an approach for caching of samples for Mars surface missions. Its bottom-loading design allows for sealing of samples in close-packed individual sleeves. It allows for transfer of samples to a sample container from a relatively coarsely controlled sampling tool by utilizing a passively compliant sample transfer funnel. The design allows for detaching the container from the rover and dropping it on the Martian surface. Using such a caching subsystem, samples can be cached in a container and left on the Martian surface for many years. The container could be retrieved and returned to Earth as part of a subsequent sample return mission or utilized in a subsequent in-situ analysis mission.

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BIOGRAPHY

Paul Backes, Ph.D. *is the Group Supervisor of the Mobility and Manipulation group in the Mobility and Robotic Systems section at Jet Propulsion Laboratory, California Institute of Technology, where he has been since 1987. He received the BSME degree from U.C. Berkeley in 1982 and Ph.D. in 1987 in Mechanical Engineering from Purdue University. Dr. Backes received the 1993 NASA Exceptional Engineering Achievement Medal for his contributions to space telerobotics, 1998 JPL Award for Excellence, 1998 NASA Software of the Year Award Sole Runner-up, and 2004 NASA Software of the Year Award. He has served as an Associate Editor of the IEEE Robotics and Automation Society Magazine.*

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